DUAL FUNCTION GROWTH MEDIUM AND STRUCTURAL SOIL FOR USE AS POROUS PAVEMENT

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Abstract

Porous grass-covered parking surfaces can reduce the quantity of urban storm water runoff and filter out potentially harmful chemicals. The objective of this study was to develop porous structural soils that promoted and sustained healthy turfgrass growth and also reduced the effects of contaminated pavement runoff. The basic medium for all soils was a 50:50 mixture of expanded shale and sand. The expanded shale component consisted of: 1) a large diameter particle (3 to 6 mm), 2) a small diameter particle (1 to 3 mm), or 3) a 50:50 mixture of the two. The basic blends were mixed with 0, 10, and 20% peat moss (v/v) and 0, 10, and 20% zeolites (v/v) and placed in 15-cm pots in a greenhouse. Bermudagrass plugs were planted in each pot. Grass growth was evaluated to determine which mixtures promoted establishment of vigorous turf. When added alone to the sand/expanded shale medium, peat moss increased bermudagrass growth and also improved plant response to added fertilizer, but the effect diminished in the absence of regular fertilization. Zeolites had no significant effect on plant growth in the absence of peat moss. Growing mediums that contained both 10-20% peat moss and 10-20% zeolites consistently produced more bermudagrass biomass than the unamended sand/expanded shale mixture. Changing the ratio of small to large diameter expanded shale in the basic medium did not affect bermudagrass yield. Very low amounts of Cd, Cu, Pb, and Zn were recovered in leachate after the addition of 10 mg metal per pot, suggesting that most heavy metals (>99%) were retained in the growing medium.

Introduction

Urban areas are increasingly covered by impermeable parking surfaces that contribute to greater quantities and intensities of storm water runoff with elevated concentrations of particulates, heavy metals, and organic chemicals (Barrett et al., 1998; Harrison and Wilson, 1985; Morrison et al., 1984; Stotz, 1987). For example, the Elm Fork Branch of the Trinity River, which passes through the Dallas metroplex, was included in the Texas 1998 Clean Water Act list of impaired water bodies due to elevated concentrations of dissolved lead. Paved and rooftop surfaces also contribute to an increasing trend in nighttime surface temperatures (Gaffen and Ross, 1999). Data from the Urban Heat Island Pilot Project, a joint USEPA/NASA venture, showed that surface temperatures of paved surfaces and rooftops was much higher than the air temperature (111°F vs. 85°F), whereas vegetated areas had lower surface temperatures (83°F) (Johnson, 1999; Lo et al., 1997).

Urban water quality could be improved by increasing the amount of vegetated surfaces within the urban limits. Use of strategically positioned grass-covered permeable surfaces for intermittent parking would decrease the amount of impermeable surfaces in the urban environment and potentially decrease the quantity and pollutant load of runoff water. When runoff water from impermeable pavement passes over a permeable surface, the concentration of pollutants is reduced (Legret et al., 1996; Pratt, 1989; Stotz and Krauth, 1994). Use of grass-covered permeable surfaces for intermittent parking would decrease the amount of impermeable surfaces in the urban environment and decrease the quantity and pollutant load of runoff water (Barrett et al., 1998). In addition to improving runoff water quality, vegetated surface will help reduce urban heat buildup (Johnson, 1999; Lo et al., 1997).

The objective of our study was to evaluate combinations of expanded shale, sand, peat moss and zeolites as growing mediums for turfgrass. We also evaluated the ability of each mixture to remove heavy metals and phosphorus from contaminated runoff water.

Materials and Methods

Porous Pavement Mixes

Table 1 shows the ingredients in each of the nine porous pavement mixes evaluated in this study. The major component of each mix (60 to 100% by volume) was a base blend that contained 50% greens-grade sand plus 50% of a equal portions of small (1 to 3 mm) and large (3 to 6 mm) diameter expanded shale (Fig. 1A). The greens-grade sand met the specifications for construction of a U.S. Golf Association putting green, containing mostly medium to course grained sand (0.25 to 1.0 mm). Expanded shale is a light-weight porous aggregate made by heating crushed shale to >1200 C. For seven of the nine porous pavement mixes, small and large diameter expanded shale were mixed in ratios of 1:1. The eighth and ninth porous pavement mixes were included in the study to determine the effect of expanded shale particle size on the porous pavement mixes. The eighth base blend was a 50:50 mixture of sand plus small diameter (1 to 3 mm) expanded shale, whereas the ninth was a 50:50 mixture of sand and large diameter (3 to 6 mm) expanded shale.

Table 1. List of ingredients in the base blend of each porous pavement mixture plus the content of peat moss and zeolites added to each base blend.

Mix No.	Base Blend	Peat Moss	Zeolites
1	50/50 Small/Large diameter shale + 50% Sand	0	0
2	50/50 Small/Large diameter shale + 50% Sand	10	0
3	50/50 Small/Large diameter shale + 50% Sand	20	0
4	50/50 Small/Large diameter shale + 50% Sand	0	10
5	50/50 Small/Large diameter shale + 50% Sand	0	20
6	50/50 Small/Large diameter shale + 50% Sand	10	10
7	50/50 Small/Large diameter shale + 50% Sand	20	20
8	50% 100LS + 50% Sand	10	10
9	50% 100SS + 50% Sand	10	10

Sphagnum peat moss is partially decomposed sphagnum moss harvested from peat bogs found mostly in Canada. Peat moss was added to the porous pavement mixes to improve water holding capacity and to provide a source or organic matter for promoting biological activity. Sphagnum peat moss was added to some of the base blends at rates of 0, 10, and 20% by volume.

Natural zeolites are aluminosilicate minerals with a unique interconnecting crystal lattice structure that gives them a large internal surface area and a very high cation exchange capacity. We added zeolites from New Mexico to the porous pavement blends for two reasons. First, we thought they would help retain fertilizer nutrients in the porous pavement mixtures so that the mixes would need less frequent fertilization. Second, we thought zeolites would absorb heavy metals from contaminated urban runoff water as it percolated through the porous pavement. Zeolites were added to the base blends at rates of 0, 10, and 20% by volume.

The various porous pavement mixes were chosen so that we could test the effect of peat moss and zeolites alone or in combination with each other. Mixes 2 and 3 showed the effects of peat moss, mixes 4 and 5 the effects of zeolites, and mixes 6 and 7 the effects of the combined ingredients. A comparison of mixes 8 and 9 showed the effect of expanded shale particle size.

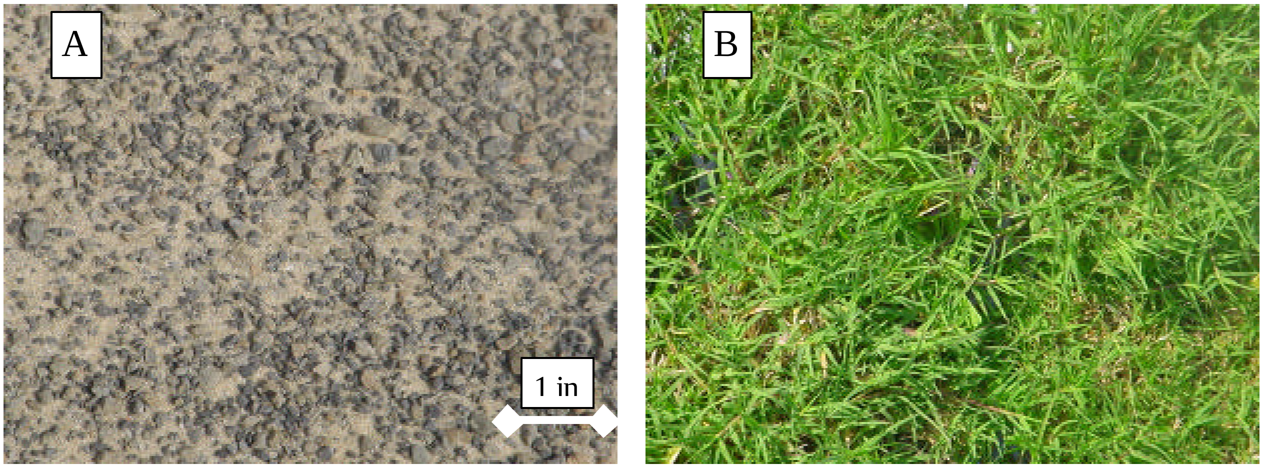

Figure 1. (A) Base blend for porous pavement mixes consisting of 50% sand plus 50% of equal portions of small (1-3 mm) and large (3-6 mm) expanded shale; and (B) bermuda grass growing on the base blend in 5-in pots.

Physical Properties

A portion of each porous pavement mix was used to determine bulk density and approximate water holding capacity. Each porous pavement mix was placed in a 1 L polyvinyl chloride leaching column of known volume and saturated with water for a period of 24 hours. Then excess water was drained from the porous pavement mix for 24 hours prior to measuring the wet weight. The mixes were then dried at 105°C for 48 hours before measuring the dry weight. Water holding capacity (equivalent to soil field capacity) was calculated on a volumetric basis using a value of 1 g/mL for water. Bulk density was equal to the oven-dry weight divided by the volume of porous pavement mix.

Grass growth

The porous pavement blends were placed in greenhouse pots measuring approximately 12.5 cm height by 10 cm depth. Bermudagrass sprigs (Cynodon dactylon [L.]) were collected from bermudagrass plots on native soil. Sprigs were washed to remove soil prior to planting 3-4 sprigs in each porous pavement pots. During the first 2 weeks after planting the sprigs, each pot received three applications of soluble 20-20-20 fertilizer for a total N, P, and K rate of 0.48, 0.21, and 0.40 g/pot, respectively. After grass was established (Fig. 1B), each pot was periodically fertilized (approximately every 200 to 260 days) with a slow-release form of 18-6-12 fertilizer at a rate of 1.08, 0.16, and 0.60 g/pot of N, P, and K, respectively. Pots were maintained in a greenhouse environment most of the time, but were periodically moved outdoors when mealy bugs *(Pseudococcus Spp.)* became a problem. Growth rates varied depending on the time of year and time after fertilizer application. Grass tissue was clipped to a 3.8 cm height whenever necessary. Clippings were oven dried at 65°C and weighed to determine biomass production.

Heavy metal and phosphorus leaching

After grass was well established on each pot, 10 mL of an aqueous solution containing 250 µg each of Cd, Cu, Pb, and Zn was added to the top of each pot. Pots were then leached with 250 mL of deionized water at 1, 3, 7, and 14 days after metal addition. The leachate volume was measured, filtered through a medium grade filter paper, and analyzed for Cd, Cu, Pb, and Zn content by atomic absorption spectroscopy. In most cases, the concentration of these heavy metals was below detection limits of the instrument. Therefore, another 750 µg of the same heavy metals was added to the top of each pot and the pots were leached with 375 mL deionized water 5 days after metal addition. Heavy metal concentrations were still very low, so two months later we added 10 mg each of Cd, Cu, Pb and Zn to each pot and leached them with 375 mL deionized water at 1 and 4 days after metal addition. In all cases, leachate volume was measured and filtered prior to subsequent analyses. To determine the effect of the porous pavement mixes on absorption of heavy metals, we calculated the cumulative amount of heavy metals leached from each pot following the three additions of heavy metals. The cumulative amount was calculated by summing the product of leachate volume and heavy metal concentration for all the leaching events. However, since we did not collect leachate every time we added water to the porous pavement mixes, the cumulative values should be interpreted as qualitative measurements rather than the total flux of heavy metals leached from the porous pavement mixes.

Another purpose for collecting leachate was to determine the fate of fertilizer P added to the porous pavement mixes. An aliquot of the same leachate sample analyzed for heavy metals was also analyzed for dissolved inorganic P content. Inorganic P was determined using the colorimetric method of Olsen and Sommers (1982). Inorganic P measurements should also be interpreted as a qualitative indicator of the ability of the porous pavement mixes to absorb P. Leachate P data was interpreted by considering the number of days the leachate was collected after the last application of fertilizer.

Results and Discussion

Physical properties

For each physical property, the nine porous pavement treatment means are presented in a single bar graph. However, the data will discussed in terms of how each specific variable (peat moss content, zeolites content, or expanded shale particle size) affected the physical property of interest. Most treatment means were compared to the simplest porous pavement mix that contained only the base blend without peat moss or zeolites. In the following bar graphs (Figs. 1, 2, and 3), the control treatment is the bar furthest to the left (Mix No. 1) with the other mixes located by increasing mix number (Table 1) to the right. For statistical purposes, the means for all nine treatments were compared simultaneously using Duncan's multiple range test. In general, significant differences among treatment means were easily discerned for all physical properties due to a low degree of variability in the data.

Bulk density

Peat moss was the ingredient that had the greatest effect on soil bulk density (Fig. 2). When added at a 10% rate (v/v), peat moss was no different that the base blend (Mix No. 2 vs. 1), but a 20% addition of peat moss

(Mix No. 3) significantly decreased bulk density. Peat moss is an organic material with a lower bulk density than mineral materials such as soil and expanded shale (Sloan, et al. 2002) Therefore, replacement of the expanded shale/sand base blend by peat moss in the porous pavement mix caused the bulk density to decrease. On the other hand, zeolites have a higher bulk density than expanded shale, which comprised 50% of the base blend, so addition of zeolites to the porous pavement mixes caused the bulk density to increase (Mixes 4 and 5 vs. 1). Addition of 10% peat moss and 10% zeolites did not significantly change bulk density of the porous pavement mix (Mix No. 6 vs. 1), probably because the addition of one negated the effect of the other. Therefore, it was somewhat unexpected to see that the porous pavement mix with the lowest bulk density was the blend that contained 20% peat moss and 20% zeolites (Mix No. 7 vs. 1). With a 20% addition of each of these ingredients, the base blend comprised only 60% of the porous pavement mix. In reality, we did not measure the final volume of the porous pavement mix after we blended the ingredients. The ingredients probably combined in such a way that there was a looser arrangement of individual particles in the final mix, especially the heavier expanded shale and sand particles. Expanded shale particle size had no effect on bulk density of the porous pavement mix (Mix No. 8 vs. 9). The bulk densities for all porous pavement mixes ranged from 1.0 to 1.4 g/cm^3, which suggested there would be no impediment to root growth.

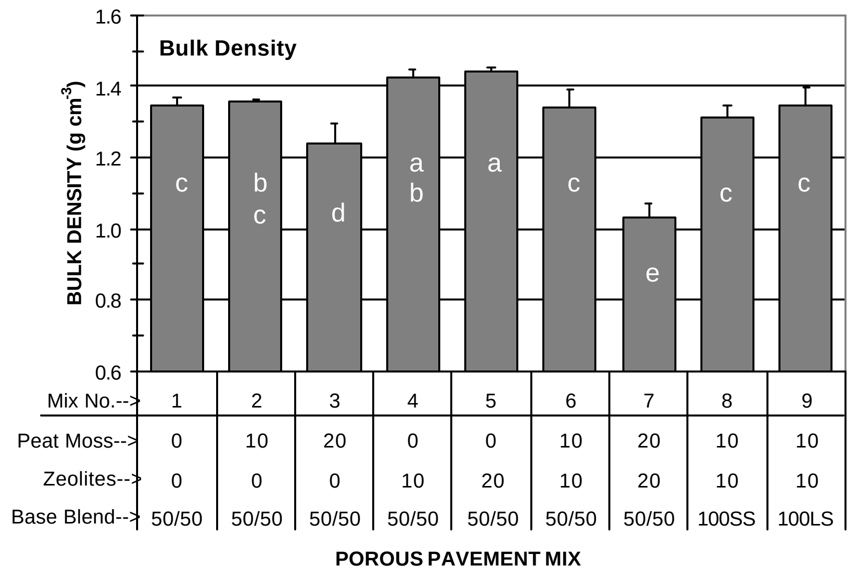

Figure 2. Effect of peat moss and zeolites content or expanded shale particle size on the bulk density of porous pavement blends.

Water Holding Capacity

Water holding capacity of the porous pavement mixes is equivalent to soil field capacity because it is the amount of water retained in the mix after all excess water has drained gravimetrically. Both the 10% and 20% additions of peat moss increased the water holding capacity of the base blend (Fig. 3) (Mixes 2 and 3 vs. 1). The 20% addition of zeolites (v/v) also increased water holding capacity of the base blend (Mix No. 5 vs. 1), but not the 10% addition (Mix No. 4 vs. 1). However, the increase in water holding capacity due to zeolites was not as great as the increase due to peat moss (Mix No. 5 vs. 3). Nus and Brauen (1991) found that sand amended with 10 to 20% peat moss retained more moisture than sand amended with equal amounts of natural zeolites. Mix No. 7, which contained 20% peat moss and 20% zeolites, exhibited the highest water holding capacity relative to all other porous pavement blends. This is consistent with the low bulk density for the same mix (Fig. 2). Apparently a combination of 20% peat moss and 20% zeolites has a greater potential to retain water than a 20% addition of either ingredient alone. Once again, it is probably related to the physical arrangement of peat moss and zeolites with the expanded shale/sand base blend. Expanded shale particle size had a small but statistically significant effect on water holding capacity of the porous pavement mix. The porous pavement mix that used only small diameter (1 to 3 mm) expanded shale in the base blend had a higher water holding capacity than the mix that used only large diameter (3 to 6 mm) expanded shale (Mix No. 8 vs. 9). This is consistent with the effect of particle size on water holding capacity of natural soils.

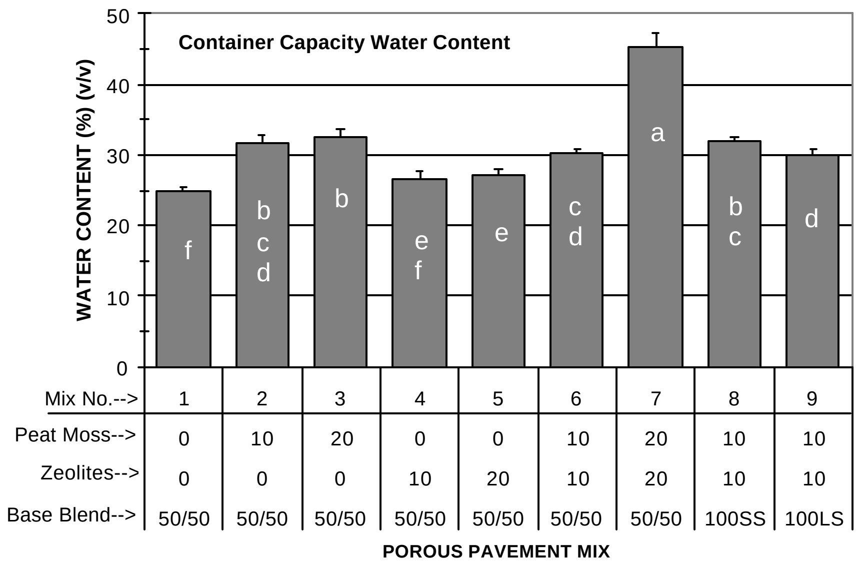

Figure 3. Effect of peat moss and zeolites content or expanded shale particle size on the water holding capacity of porous pavement blends.

Grass Growth

Bermudagrass clippings were collected twenty two times during a 26-month period. After 15 clippings, we noticed the pots were infected with mealy bugs *(Pseudococcus Spp.)*, so we clipped the bermudagrass to the crown level. Mealy bugs continued to be a problem, so after the nineteenth harvest, porous pavement pots were moved outside the greenhouse. Bermudagrass was clipped at intervals ranging from 14 to 65 days, depending on the rate of growth. Since we were interested in the long term ability of the porous pavement blends to sustain plant growth, we calculated the cumulative clipping weights per pot (Table 2). Peat moss was the only ingredient that significantly increased bermudagrass clipping weights compared to the unamended base blend. Zeolites had no effect on bermudagrass growth when added to the base blend alone or with peat moss.

Fertility was the main factor controlling the rate of bermudagrass growth. Bermudagrass required clipping at 2 to 3 week intervals during the first two months after fertilization, but less frequently after that. Pots were fertilized only five times during 26 months. Therefore, the structural soil was probably depleted of nutrients prior to the each fertilization. The length of time between fertilizations ranged from 200 to 260 days. After fertilization, the structural soil blends responded differently to the added nutrients. Those porous pavement blends that contained peat moss or peat moss plus zeolites responded to fertilizer more favorably than those blends that did not in terms of bermudagrass clipping weights (data not shown). In general, there was no difference in bermudagrass clipping weights among the various porous pavement blends beyond 80 to 90 days after the last fertilizer application.

Table 2. Treatments 1 through 7 show the effect of peat moss and zeolite on cumulative bermudagrass clipping rates when mixed with a 50:50 blend of small (1-3 mm) and large (3-6 mm) diameter expanded shale at rates of 10 and 20% (based on volume). Treatments 8 and 9 show the effect of expanded shale diameter on cumulative bermudagrass clipping weights.

TrtNo	Base Blend†	Peat Moss Content	Zeolite Content	Cumulative Clipping Weights	SD‡
		(%)	(%)	(g/pot)	
1	50/50	0	0	91.7	17.0
2	50/50	10	0	98.7	9.8
3	50/50	20	0	107.9	9.0
			Linear effect of peat moss	**	
4	50/50	0	10	100.9	18.0
5	50/50	0	20	95.1	13.5
			Linear effect of zeolites	NS	
6	50/50	10	10	106.2	9.1
7	50/50	20	20	116.9	20.6
		Linear effect of combined peat moss and zeolites		**	
8	100SSh	10	10	110.3	6.2
9	100LSh	10	10	106.3	12.0
		Linear effect of expanded shale diameter		NS	

NS, ** Not significant and significant at the 0.05 level of probability, respectively.
† Base blends were mixed in a 50:50 ratio with sand before mixing with the other ingredients.
‡ Standard deviation of the treatment mean.

Leachate Chemistry

Leachate was not collected continuously throughout the study, but rather at specific times in relation to the addition of heavy metals to the pots. We generally collected leachate for several days after heavy metals were added. The leachate was analyzed for heavy metals (Cd, Pb, and Zn) and inorganic phosphorus. Additional leachate was periodically collected to assess the effect of fertilization on inorganic P concentration and other nutrients (data not shown). Since we did not collect all leachate from the porous pavement mixes, we cannot calculate a mass balance for the heavy metals and nutrients added to the pots. However, the leachate data is a good indicator of the effect of the porous pavement ingredients on the leaching loss of potential environmental pollutants.

Heavy metals

Our hypothesis was that the addition of zeolites to the porous pavement mixes would increase their ability to remove heavy metals from contaminated runoff water. The results shown in Figure 4 for Cd, Pb, and Zn are somewhat inconclusive. In most cases, the concentrations of heavy metals in the leachate waters were very close to the analytical detection limits. This introduced a high degree of variability in the data and made it more difficult to discern significant differences among porous pavement mixes. In the case of Cd, neither zeolites nor peat moss affected the amount of Cd in leachate relative to the unamended base blend (Mix Nos. 2 to 7 vs. Mix No. 1). For some reason, the two porous pavement mixes that contained only small or large expanded shale in the base blend (Mix Nos. 8 and 9) resulted in significantly higher Cd concentrations in the leachate water. The reason for this is unclear, but it could be related to the physical arrangement of particles in the porous pavement blend. The results for Zn were very similar to those for Cd. Essentially, peat moss and zeolites did not affect the amount of Zn in leachate water, either when applied alone or together. Only expanded shale particle size affected the amount of Zn. Both small and large diameter expanded shale increased leachate Zn when they were the only form of expanded shale in the base blend.

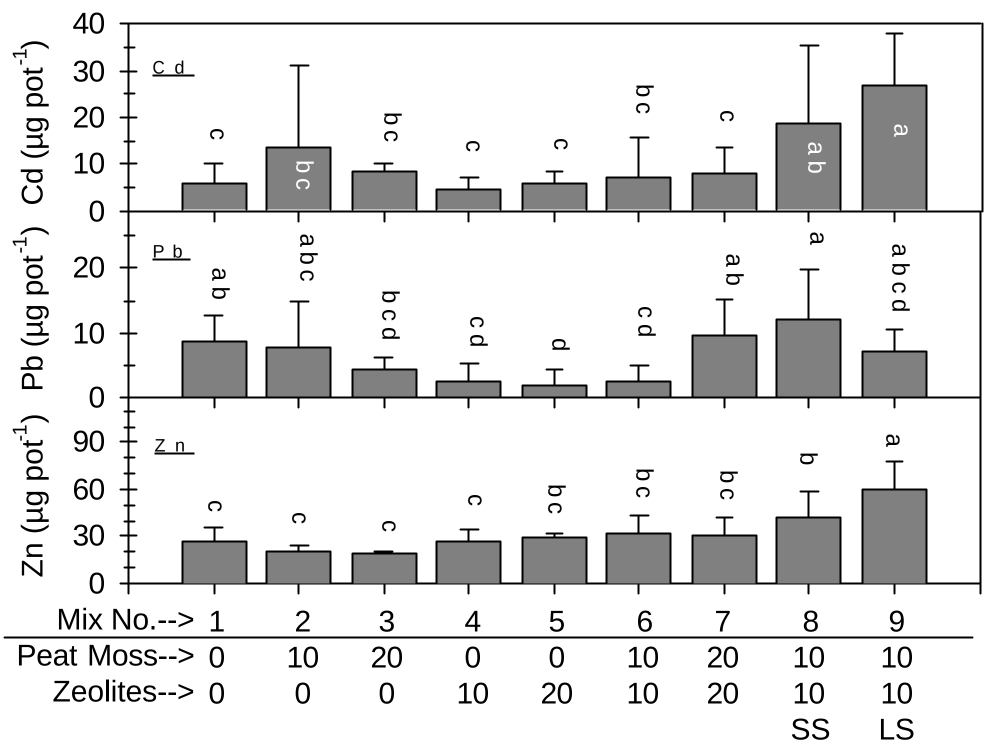

Figure 4. Concentrations of Cd, Pb, and Zn in leachate from the porous pavement mixes after applying 10 mg of each heavy metal to the top of each pot.

Lead was the only heavy metal that appeared to be affected by the presence of zeolites in the porous pavement mix (Fig. 4). Leachate from porous pavement mixes that contained 10% and 20% zeolites without peat moss (Mix Nos. 4 and 5) contained significantly lower concentrations of Pb than the unamended base blend (Mix No. 1). Leachate from the porous pavement mix that contained both 10% peat moss and 10% zeolites (Mix No. 6) also had lower levels of Pb than the unamended base blend, but not the mix that contained 20% of both ingredients (Mix No. 7).

In general, the effect of zeolites on heavy metal removal from leachate water is still unclear based on the results of this study. Zeolites have been used to successfully remove heavy metals from wastewater (Ibrahim et al., 2002), so it is logical to expect them to remove heavy metals from contaminated runoff water. However, there is a high degree of variability in the properties of natural zeolites (Mumpton, 1999), so some zeolites sources may be better than others. In our study, the failure to see definite effects due to the inclusion of zeolites in the porous pavement mixes was probably due to a combination of two factors. First, the amount of zeolites added to the porous pavement blends may have been insignificant compared to the overall porous pavement matrix, and second, the amount of heavy metals added to the top of each column was very low.

Phosphorus

Grass growing on porous pavement would require periodic fertilization in order to maintain healthy growth. Fertilizer nutrients, especially phosphorus, can be environmental contaminants when present in runoff or drainage water at high concentrations. For that reason, we looked at phosphorus concentrations in leachate water, particularly in relation to when the fertilizer was applied. Table 2 shows concentrations of P in the leachate from each porous pavement blend at times ranging from 5 to 254 days after fertilization. From 5 to 97 days after fertilization, there was a significant difference among porous pavement mixes in the levels of P in leachate water. Peat moss was the ingredient that had the greatest effect on P leaching. Leachate P concentrations increased with the amount of peat moss in the porous pavement mix. Zeolite content and expanded shale particle size had little effect on the amount of P leached from the porous pavement mix. Time after fertilization also had a significant effect on the amount of P leached. The amount of P leached decreased with time and by 162 days after fertilizer application, there was no significant difference among the porous pavement blends. In general, inorganic P concentrations were relatively low in the porous pavement leachate, suggesting that most of the fertilizer P remained in the porous pavement matrix or was removed by grass. Sloan et al. (2000) found that expanded shale has a relatively high capacity to adsorb fertilizer P.

Table 3. Effect of porous pavement ingredients and days after last fertilization application on the P concentration in leachate water.

				Leachate P Concentration					
	Base	Peat		Days after last fertilizer application					
Mix No.	Blend	Moss	Zeo	5	18	40	97	162	254
		(%)	(%)	(mg/L)					
1	50/50	0	0	0.192	0.162	0.181	0.447	0.243	0.473
2	50/50	10	0	0.244	0.115	0.141	0.129	0.278	0.483
3	50/50	20	0	0.435	0.316	0.377	0.242	0.425	0.563
4	50/50	0	10	0.274	0.090	0.163	0.198	0.385	0.513
5	50/50	0	20	0.414	0.225	0.295	0.416	0.427	0.494
6	50/50	10	10	0.333	0.149	0.337	0.166	0.306	0.613
7	50/50	20	20	1.203	0.491	0.481	0.658	0.434	0.467
8	100LS	10	10	1.299	0.468	0.403	0.353	0.419	0.652
9	100SS	10	10	0.856	0.191	0.285	0.061	0.220	0.719
	LSD†			0.274	0.134	0.188	0.263	0.182	0.184
	p-level‡			***	***	**	***	Ns	ns

† Least significant difference between treatment means.
‡ Level of significance.
ns, **, *** Not significant or significant at the 0.01 and 0.001 level of probability, respectively.

Conclusions

Our study evaluated the ability of 9 porous pavement mixtures to maintain healthy grass growth and to remove potential contaminants from urban runoff water. Sphagnum peat moss provided the greatest benefits to plant growth but had little effect on the ability of the porous pavement blends to remove contaminants from polluted runoff. Zeolites provided little benefit to plant growth, but showed some potential to remove heavy metals from runoff water. Further testing is needed with higher concentrations of heavy metals. The expanded shale particle sizes tested in this study had no effect on grass growth and there was not effect of particle size on the amount of heavy metals leached. Field scale testing of the porous pavement mixes is needed in order to evaluate their performance under actual environmental conditions and to begin to develop best management practices for turfgrass growing on porous pavement surfaces. Since the porous pavement blends are proposed as temporary parking surfaces, engineering tests are needed to determine load-bearing strengths as it relates to the handling of vehicular weights.

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